THE

Relations of Civil Engineering

TO

Other Branches of Science.

AN ADDRESS

TO THE INTERNATIONAL CONGRESS OF ARTS AND SCIENCE AT THE UNIVERSAL EXPOSITION, ST. LOUIS, MO.

SEPTEMBER 21, 1904.

BY

J. A. L. WADDELL, D. Sc., LL. D.

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The topic set for this address is "The Relations of Civil Engineering to Other Branches of Science." In its broad sense Civil Engineering includes all branches of engineering except, perhaps, the military. This is its scope as recognized by two of the highest authorities, viz., the American Society of Civil Engineers and the Institution of Civil Engineers of Great Britain; for these two societies of *Civil* Engineers admit to their ranks members of all branches of engineering. It is evident, though, from a perusal of the Programme of this Congress that the Organizing Committee intended to use the term in a restricted sense, because it has arranged for addresses on mechanical, electrical, and mining engineering. But what are the proper restrictions of the term is, up to the present time, a matter of individual opinion, no authority having as yet attempted definitely to divide engineering work among the various branches of the profession. To do so would, indeed, be a most difficult undertaking; for not only do all large constructions involve several branches of engineering, but also the profession is constantly being more minutely divided and

subdivided. For instance, there are recognized to-day by the general public, if not formally by the profession, the specialities of architectural, bridge, chemical, electrical, harbor, highway, hydraulic, landscape, marine, mechanical, metallurgical, mining, municipal, railroad, and sanitary engineering, and possibly other divisions; and the end is not yet, for the tendency of modern times in all walks of life is to specialize.

Between Tredgold's broad definition of civil engineering, which includes substantially all the applied sciences that relate to construction, and the absurdly narrow definition which certain engineers have lately been endeavoring to establish during the course of a somewhat animated discussion and which would confine civil engineering to dealing with stationary structures only, there must be some method of limitation that will recognize the modern tendency towards specialization without reducing the honored profession of civil engineering to a mere subdivision of applied mechanical science.

Without questioning in any way the correctness of the Tredgold definition, civil engineering will be assumed, for the purposes of this address, to include the design and construction of bridges; extensive and difficult foundations; tunneling; retaining walls, sea-walls, and other heavy masonry; viaducts; wharves; piers; docks; river improvement; harbors and waterways; water supply; sewerage; filtration; treatment of refuse; highway construction; canals; irrigation works; dams; geodetic work; surveying; railways (both steam and electric); gas works; manufacturing plants; the general design and construction of plants for the production of power (steam, electric, hydraulic, and gaseous); the general design and construction of cranes, cableways, breakers, and other mining structures; the heavier structural features of office buildings and other large buildings that carry heavy loads; the general problems of transportation, quarrying, and the handling of heavy materials; and all designing and construction of a similar nature.

In contradistinction, mechanical engineering should include the design and construction of steam engines, machine tools, locomotives, hoisting and conveying machinery, cranes of the usual types, rolling-mill machinery, blast-furnace machinery, and, in

fact, all machinery which is designed for purely manufacturing purposes.

Electrical engineering should include all essentially electrical work, such as the designing, construction, and operation of telephone and telegraph lines; electric light plants; dynamos; motors; switchboards; wiring; electric devices of all kinds; transmission lines; cables (both marine and land); and storage batteries.

Mining engineering should include all under-ground mining work; means for handling the products of mines; roasting, smelting, milling, stamping, and concentrating of ores; drainage and ventilation of mines; disposal of mine refuse; and similar problems.

It is impracticable to draw hard-and-fast lines between the various branches of engineering, because, as before indicated, nearly all large constructions involve several specialties, consequently no specialist can confine his attention to a single line of work to the exclusion of all other lines. For instance, the bridge engineer encounters mechanical and electrical engineering problems in designing movable bridges; railroading in approaches to bridges; river improvement in the protection of piers and abutments; highway construction in the pavement of wagon bridges; architecture in the machinery houses of swing spans; hydraulic engineering in guarding bridges against fire; and chemistry and metallurgy in testing materials. The railroad engineer encounters architecture and structural engineering in depots, roundhouses, and other buildings; hydraulic problems in pumping plants and bank protection; mechanical engineering in interlocking plants; and electrical engineering in repair-shop machinery. The mining engineer invades the field of mechanical and electrical engineering in his hoisting, ventilating, and transporting machinery; deals with civil engineering in his surveys; and encounters chemistry and metallurgy in testing ores. Similarly it might be shown that all branches of engineering overlap each other and are interdependent.

It was the general opinion among scientists not many years ago that engineering was neither a science nor a profession, but merely a trade or business; and even to-day there are a few learned men who hold to this notion—some of them, *mirabile*

dictu, being engineers; but that such a view is entirely erroneous is now commonly conceded. He is an ill-informed man who to-day will deny that civil engineering has become one of the learned professions. Its advances in the last quarter of a century have been truly gigantic and unprecedented in the annals of professional development. It certainly can justly lay claim to being the veritable profession of progress; for the larger portion of the immense material advancement of the world during the last century is due primarily and preeminently to its engineers.

It must be confessed that half a century ago engineering was little better than a trade, but by degrees it advanced into an art, and to-day, in its higher branches at least, it is certainly a science and one of the principal sciences.

The sciences may be divided into two main groups, viz., "Pure Sciences" and "Applied Sciences."

The "Pure Sciences" include:—

1st. Those sciences which deal with numbers and the three dimensions in space, the line, the surface, and the volume, or in other words "Mathematics."

2d. Those sciences which deal with inorganic matter, its origin, structure, metamorphoses, and properties; such as geology, petrology, chemistry, physics, mineralogy, geography, and astronomy.

3d. Those sciences which deal with the laws, structure, and life of organic matter; such as botany, zoology, entomology, anatomy, physiology, and anthropology.

4th. The social sciences; such as political economy, sociology, philosophy, history, psychology, politics, jurisprudence, education, and religion.

"Applied Sciences" include:—

1st. Those which relate to the growth and health of organic matter; such as medicine, surgery, dentistry, hygiene, agriculture, floriculture, and horticulture.

2nd. Those which deal with the transformation of forces and inorganic matter, viz., the various lines of engineering,—civil, mechanical, electrical, mining, marine, chemical, metallurgical, architectural, etc.

3rd. Those which relate to economics; such as industrial or-

ganizations and manufactures, transportation, commerce, exchange, and insurance.

Some writers make no distinction between the terms "Political Economy" and "Economics," but in this address they are divided, the former relating to broad subjects of national importance and the latter to minor matters and to some of the details of larger ones. For instance, currency, the national debt, banking, customs, taxation, and the subsidizing of industries pertain to "Political Economy," while economy of materials in designing and of cost of labor in construction, supplanting of hand power by machinery, systemization of work of all kinds, adjustment of grades and curvature of railroads to traffic, and time-and-labor saving devices come under the head of "Economics."

The distinctions between the pure and the applied sciences are at times extremely difficult to draw, for one science often merges almost imperceptibly into one or more of the others.

The groups of pure sciences that have been enumerated may be termed

The Mathematical Sciences,
The Physical Sciences,
The Physiological Sciences, and
The Social Sciences,

while the groups of applied sciences may be called

The Organic Sciences,
The Constructive Sciences, and
The Economic Sciences.

In what follows the preceding nomenclature will be adopted.

The terming of engineering the "Constructive Science" is a happy conception, for engineering is truly and almost exclusively the science of construction. The functions of the engineer in all cases either are directly constructive or tend towards construction.

The engineer has ever had a due appreciation of all the sciences, imagination to see practical possibilities for the results of their findings, and the common-sense power of applying them to his own use.

Pure science (barring perhaps political economy) is not concerned with financial matters, and its devotees often look down

with lofty disdain upon everything of a utilitarian nature, but engineering is certainly the science most directly concerned with the expenditure of money. The engineer is the practical man of the family of scientists. While he is sufficiently well informed to be able to go up into the clouds occasionally with his brethren, he is always judicious and comes to earth again. In all his thoughts, words, and acts he is primarily utilitarian. It is true that he bows down to the goddess of mathematics, but he always worships from afar. It is not to be denied that mathematics is the mainstay of engineering; nevertheless the true engineer pursues the subject only so far as it is of practical value, while the mathematician seeks new laws and further development of the science in the abstract. The engineer does not trouble himself to consider space of four dimensions, because there are too many things for him to do in the three-dimension space in which he lives. Non-Euclidian geometry is barred from his mind for a fuller understanding of the geometry which is of use to ordinary mankind. The mathematician demonstrates that the triangle is the sole polygonal figure which cannot be distorted, while the engineer, recognizing the correctness of the principle, adopts it as the fundamental, elementary form for his trusses. The mathematician endeavors to stretch his imagination so as to grasp the infinite, but the engineer limits his field of action to finite, tangible matters.

The geologist, purely studious, points out what he has deduced about the construction of the earth; but the engineer makes the mine pay.

The chemist discovers certain facts about the effects of different elements in alloys; but the engineer works out and specifies a new material for his structures. Again, the chemist learns something about the action of clay combined with carbonate of lime when water is added, and from this discovery the engineer determines a way to produce hydraulic cement.

The physicist evolves the theory of the expansive power of steam, and the engineer uses this knowledge in the development of the steam engine. Again, the physicist determines by both theory and experiment the laws governing the pressures exerted by liquids, and the engineer applies these laws to the construc-

tion of dams and ships.

The botanist with his microscope studies the form and construction of woods, while the engineer by experimentation devises means to preserve his timber.

The biologist points to bare facts that he has discovered, but the engineer grasps them and utilizes them for the purification of water supplies.

In short, the aim of pure science is discovery, but the purpose of engineering is usefulness.

The delvers in the mysterious laboratories, the mathematical gymnasts, the scholars poring over musty tomes of knowledge, are not understood by the work-a-day world, nor do they understand it. But between stands the engineer with keen and sympathetic appreciation of the value of the work of the one and a ready understanding of the needs and requirements of the other; and by his power of adaptability he grasps the problems presented, takes from the investigators their abstract results, and transforms them into practical usefulness for the world.

The work of the engineer usually does not permit him to make very extensive researches or important scientific discoveries; nor is it often essential to-day for him to do so, as there are numerous investigators in all lines whose object is to deduce abstract scientific facts; nevertheless there comes a time occasionally in the career of every successful engineer when it is necessary for him to make investigations more or less abstract, although ultimately utilitarian; consequently it behooves engineers to keep in touch with the methods of scientific investigation, in order that they may either perform desired experiments themselves, or instruct trained investigators how to perform them.

The engineer must be more or less a genius who invents and devises ways and means of applying all available resources to the uses of mankind. His motto is "utility," and his every thought and act must be to employ to the best advantage the materials and conditions at hand. To be able to accomplish this object he must be thoroughly familiar with all useful materials and their physical properties as determined by the investigations of the pure scientists.

Many well known principles of science have lain unused for

ages awaiting the practical application for which they were just suited. The power of steam was known long before the practical mind of Watt utilized it in the steam engine.

The engineer is probably an evolution of the artisan rather than of the early scientist. His work is becoming more scientific because of his relations and associations with the scientific world. These relations of the engineer to the sciences are of comparatively recent origin, and this fact accounts for the rapid development in the engineering and industrial world of the past half century. The results of this association have been advantageous to both the engineer and the pure scientist. The demands of the engineers for new discoveries have acted as an incentive for greater effort on the part of the investigators. In many instances the engineer is years in advance of the pure scientist in these demands; but, on the other hand, there are, no doubt, many valuable scientific facts now available which will yet work wonders when the engineer perceives their practical utility.

The engineer develops much more fully the faculty of discernment than does the abstract scientist, he is less visionary and more practical, less exacting and more commercial.

It is essential to progress that large stores of scientific knowledge in the abstract be accumulated and recorded in advance by the pure scientists, so that as the engineer encounters the necessity for their use he can employ them to the best advantage. The engineer must be familiar with these stores of useful knowledge in order to know what is available. This forms the scientific side of the engineer's work. While he must know what has been done by investigators, it is not absolutely necessary that he know how to make all such researches for himself; although, as before stated, there are times in an engineer's practice when such knowledge will not come amiss.

As engineers are specializing more and more, each particular specialty becomes more closely allied with the sciences that most affect it; consequently, to ensure the very best and most economic results in his work the engineeer must keep in close touch with all of the scientific discoveries in his line.

The early engineers, owing to lack of scientific knowledge, took much greater chances in their constructions than is necessary

for up-to-date, modern engineers. There is now no occasion for an engineer to make any hazardous experiments in his structures, because by careful study of scientific records he can render his results certain.

In future the relations between engineers and the pure scientists will be even closer than they are to-day, for as the problems confronted by the engineer become more complex and comprehensive the necessity for accurate knowledge will increase.

The technical training now given engineers involves a great deal of the purely scientific; and it is evident that this training should be so complete as to give them a comprehensive knowledge of all the leading sciences that affiliate with engineering. There is no other profession that requires such a thorough knowledge of nature and her laws.

Of all the various divisions and sub-divisions of the sciences hereinbefore enumerated and of those tabulated in the Organizing Committee's "Programme," the following only are associated at all closely with civil engineering:—

Mathematics.
Geology.
Petrology.
Chemistry.
Physics.
Mineralogy.
Geography.
Astronomy.
Biology.
Botany.
Political Economy.
Jurisprudence.
Education.
Economics.

Attention is called to the fact that this list contains a number of divisions from the four main groups of pure sciences, viz., the mathematical, physical, physiological, and social, and but one division (economics) from the three groups of applied sciences, viz., the organic, constructive, and economic. The reasons why so little attention is to be given to the relation between civil engi-

neering and the applied sciences are, first, in respect to organic science, there is scarcely any relation worth mentioning between this science and civil engineering, and, second, because the interrelations between civil engineering and other divisions of constructive science have already been treated in this address.

Of all the pure sciences there is none so intimately connected with civil engineering as mathematics. It is not, as most laymen suppose, the whole essence of engineering, but it is the engineer's principal tool. Because technical students are drilled so thoroughly in mathematics and because so much stress is laid upon the study of calculus, it is commonly thought that the higher mathematics are employed constantly in an engineer's practice; but, as a matter of fact, the only branches of mathematics that a constructing engineer employs regularly are arithmetic, geomety, algebra, and trigonometry. In some lines of work logarithms are used often, and occasionally in establishing a formula the calculus is employed; but the engineer in active practice soon pretty nearly forgets what analytical geometry and calculus mean. As for applied mechanics, which, as the term is generally understood, is a branch of mathematics (although it involves also physics and other sciences), the engineer once in a while has to take down his old text-books to look up some principle that he has encountered in his reading but has forgotten. Strictly speaking, though, engineers in their daily tasks utilize applied mechanics, almost without recognition; for stresses, moments, energy, moments of inertia, impact, momentum, radii of gyration, etc., are all conceptions of applied mechanics; and these are terms that the engineer employs constantly.

There are some branches of the higher mathematics of which as yet engineers have made no practical use, and prominent among these is quaternions. When it first appeared the conciseness of its reasoning and its numerous short-cuts to results gave promise of practical usefulness to engineers, but thus far the promise has not been fulfilled.

Notwithstanding the fact that the higher mathematics are of so little use to the practicing engineer, this is no reason why their study should be omitted from or even slighted in the technical schools; because when an engineer has need in his work for the

higher mathematics he needs them badly; besides, the mental training that their study involves is almost a necessity for an engineer's professional success.

Geology (with its allied branch, or more strictly speaking subdivision, petrology) and civil engineering are closely allied. Civil engineers are by no means so well versed in this important science as they should be. This, perhaps, is due to the fact that the instruction given on geology in technical schools is mainly from books, hence most graduates find difficulty in naming properly the ordinary stones that they encounter, and are unable to prognosticate with reasonable assurance concerning what a proposed cutting contains.

Geology is important to the civil engineer in tunneling, railroading, foundations, mining, water-supply, and many other lines of work; consequently, he needs to receive at his technical school a thorough course in the subject given both by text-book and by field instruction.

A knowledge of petrology will enable the engineer to determine readily whether building stone contains iron which will injure its appearance on exposure, or feldspar which will disintegrate rapidly under the action of the weather or of acids from manufacturing establishments.

Next to mathematics, physics is undoubtedly the science most essential to civil engineering. The physicist discovers and formulates the laws of nature, the engineer employs them in "directing the sources of power in nature for the use and convenience of man." The forces of gravitation, adhesion, and cohesion; the pressure, compressibility, and expansibility of fluids and gases; the laws of motion, curvilinear, rectilinear, accelerated, and retarded; momentum; work; energy; the transformation of energy; thermodyamics; electricity; the laws of wave motion; the reflection, refraction, and transmission of light; and the mass of other data furnished by the physicist form a large portion of the first principles of civil engineering.

The function of applied mechanics is to establish the fundamental laws of physics in terms suitable for service, and to demonstrate their applicability to engineering construction.

Chemistry is a science that enters into closer relations with

civil engineering than does any other science except mathematics and physics, and as the manufacture of the materials of engineering approaches perfection the importance of chemistry to engineers increases. Within a comparatively short period the chemist has made it possible by analyzing and selecting the constituents to control the quality of cast iron, cast steel, rolled steel, bronze, brass, nickel steel, and other alloys. The engineer requires certain physical characteristics in his materials, and obtains them by limiting the chemical constituents in accord with data previously furnished by the chemist. The proper manufacture of cement requires the combined skill and knowledge of the chemist and the mechanical engineer.

In water supply the chemist is called in to determine the character and amounts of the impurities in the water furnished or contemplated for use. The recent discovery that the introduction of about one part of sulphate of copper in a million parts of water will effectively dispose of the algæ, which have long given trouble, is a notable instance of the increasing interdependence of these two branches of science, as is also the fact that the addition to water of a small amount of alum will precipitate the earthy matter held in suspension without leaving in it any appreciable trace of the reagent.

In the purification of water and sewage, in the selection of materials which will resist the action of acids and the elements, and in the manufacture of alloys to meet various requirements, a thorough knowledge of chemistry is essential.

A knowledge of mineralogy is requisite for a clear understanding of the nature of many materials of construction, but is otherwise of only general interest to civil engineers.

Geography in its broad sense is related to civil engineering in some of its lines, for instance, geodesy and surveying, but generally speaking there is not much connection between these two branches of science.

Astronomy is perhaps more nearly related to civil engineering than is geography, although it is so related in exactly the same lines, for the railroad engineer on a long survey must occasionally check the correctness of his alignment by observations of Polaris, and the coast surveyor locates points by observations of

the heavenly bodies.

Biology is allied to civil engineering mainly through bacteriology as applied to potable water, the treatment of sewage to prevent contamination of streams, and the sanitation of the camps of surveying and construction parties. The treatment of sewage has been given much more thorough study abroad than in this country, but the importance of its bearing upon life in the large cities of America is becoming better understood; consequently the progressive sanitary engineer should possess a thorough knowledge of bacteriology. In important cases, such as an epidemic of typhoid fever, the specialist in bacteriology would undoubtedly be called in; but a large portion of the work of preventing or eradicating bacterial diseases will fall to the lot of the sanitary engineer.

Botany comes in touch with civil engineering mainly, if not solely, in the study of the various woods used in construction, although it is a fact that a very intimate knowledge of this pure science might enable a railroad engineer or surveyor to determine approximately the characters of soils from the plants and trees growing upon them. A knowledge of botany is of no great value to the civil engineer, and much time is often wasted on its study in technical schools.

Political economy is a science that at first thought one would be likely to say is not at all allied to civil engineering; but if he did so, he would be mistaken, because political economy certainly includes the science of business and finance, and civil engineering is most assuredly a business as well as a profession; besides, the leading engineers usually are either financiers themselves or advisers to financiers. Great enterprises are often evolved, studied, financed, and executed by engineers. How important it is then that they understand the principles of political economy, especially in its relation to engineering enterprises! It is only of late years that technical students have received much instruction in this branch of social science, and the ordinary technical school curriculum to-day certainly leaves much to be desired in respect to instruction in political economy.

Jurisprudence and civil engineering are closely allied in that engineers of all lines must understand the laws of business and

the restrictions that are likely to be placed upon their constructions by municipal, county, state, and federal laws. While most engineering schools carry in their lists of studies the "Laws of Business," very few of them devote anything like sufficient attention to this important branch of science.

Are the sciences of civil engineering and education in any way allied? Aye, that they are! and far more than most people think, for there is no profession that requires as much education as does civil engineering. Not only must the would-be engineer study the various pure and applied sciences and learn a great mass of technical facts; but he must also have in advance of all this instruction a broad, general education—the broader the better, provided that no time be wasted on useless studies, such as the dead languages.

The science of education is so important a subject for civil engineers that all members of the profession in North America, more especially those of high rank, ought to take the deepest interest in the development of engineering education, primarily by joining the special society organized for its promotion, and afterwards by devoting some of their working time to aid this society in accomplishing its most praiseworthy objects.

The science of economics and that of civil engineering are, or ought to be, in the closest possible touch; for true economy in design and construction is one of the most important features of modern engineering. Every high-class engineer must be a true economist in all the professional work that he does, for unless one be such, it is impossible to-day for him to rise above mediocrity.

True economy in engineering consists in always designing and building structures, machines, and other constructions so that, while they will perform satisfactorily in every way all the functions for which they are required, the sum of their first cost and the equivalent capitalized cost for their maintenance, operation, and repairs shall be a minimum. The ordinary notion that the structure or machine which is least in first cost must be the most economical is a fallacy. In fact, in many cases, just the opposite is true, the structure or machine involving the largest first cost being often the cheapest.

Economics as a science should be taught thoroughly to the student in the technical school, then economy in all his early work should be drilled into him by his superiors during his novitiate in the profession, so that when he reaches the stage where he designs and builds independently, his constructions will invariably be models of true economy.

It has been stated that the relations between civil engineering and many of the pure sciences are very intimate, that the various branches of engineering, although becoming constantly more and more specialized, are so interdependent and so closely connected that they cannot be separated in important constructions, that the more data the pure scientists furnish the engineers the better it is for both parties, and that a broad, general knowledge of many of the sciences, both pure and applied, is essential to great success in the engineering profession.

Such being the case, the question arises as to what can be done to foster a still closer affiliation between engineering and the other sciences, and how engineers of all branches and the pure scientists can best be brought into more intimate relations, in order to advance the development of the pure sciences, and thus benefit the entire world by increasing the knowledge and efficiency of its engineers.

One of the most effective means is to encourage the creation of such congresses as the one that is now being held, and to so organize them and arrange their various meetings as to secure the greatest possible beneficial results.

Another is for such societies as the American Association for the Advancement of Science and the Society for the Promotion of Engineering Education to take into their membership engineers of good standing, and induce them to share the labors and responsibilities of the other members.

Conversely, the various technical societies should associate with them by admission to some dignified grade (other, perhaps, than that of full member) pure scientists of high rank and specialists in other branches of constructive science, and should do their best to interest such gentlemen in the societies' objects and development.

A self-evident and most effective method of accomplishing the

desired result is to improve the courses of study in the technical schools in every possible way; for instance, by bringing prominent scientists and engineers to lecture to the students and to tell them just how scientific and professional work of importance is being done throughout the world, by stimulating their ambition to rise in their chosen professions, by teaching them to love their work instead of looking upon it as a necessary evil, and by offering prizes and distinctions for the evidence of superior and effective mental effort on the part of both students and practicing engineers.

There has lately been advanced an idea which, if followed out, would aid the development of engineering more effectually than any other possible method, and incidentally it would bring into close contact scientists in all branches related directly or indirectly to engineering. It is the establishment of a great postgraduate school of engineering in which should be taught in every branch of the profession the most advanced subjects of all existing knowledge that is of real, practical value, the instructors being chosen mainly from the leading engineers in each specialty, regardless of the cost of their services. Such specialists would, of course, be expected to give to this teaching only a few weeks per annum, and a corps of regular professors and instructors, who would devote their entire time and energies to the interests of the school would be required. These professors and instructors should be the best that the country possesses, and the inducements of salary and facilities for investigation that are provided should be such that no technical instructor could afford to refuse an offer of a professorship in this school.

Every modern apparatus needed for either instruction or original investigation should be furnished; and arrangements should be made for providing means to carry out all important technical investigations.

It should be the duty of the regular faculty to make a special study of engineering literature for the benefit of the profession; to prepare annual indices thereof; to put into book form the gist of all technical writings in the transactions of the various engineering societies and in the technical press that are worthy of being preserved and recorded in this way, so that students and

engineers shall be able to search in books for all the data they need instead of in the back files of periodicals; to translate or assist in the translation of all engineering books in foreign languages, which, in the opinion of competent experts, would prove useful to engineers or to the students of the school; and to edit and publish a periodical for the recording of the results of all investigations of value made under the auspices of the institution.

In respect to what might be accomplished by such a post-graduate school of engineering the following quotation is made from the pamphlet containing the address in which the project was advanced:—*

"The advantages to be gained by attendance at such a post-graduate school as the one advocated are almost beyond expression. A degree from such a school would always ensure rapid success for its recipient. Possibly for two or three years after taking it a young engineer would have less earning capacity than his classmates of equal ability from the lower technical school, who had gone directly into actual practice. However, in five years he certainly would have surpassed them, and in less than ten years he would be a recognized authority, while the majority of the others would be forming the rank and file of the profession, with none of them approaching at all closely in reputation the more highly educated engineer.

"But if the advantages of the proposed school to the individual are so great, how much greater would be its advantages to the engineering profession and to the entire nation! After a few years of its existence there would be scattered throughout the country a number of engineers more highly trained in the arts and sciences than any technical men who have ever lived; and it certainly would not take long to make apparent the impress of their individuality and knowledge upon the development of civil engineering in all its branches, with a resulting betterment to all kinds of constructions and the evolution of many new and important types.

"When one considers that the true progress of the entire civilized world is due almost entirely to the work of its engineers, the importance of providing the engineering profession with the highest possible education in both theoretical and practical lines cannot be exaggerated.

"What greater or more worthy use for his accumulated wealth could an American multi-millionaire conceive than the endowment and establishment of a post-graduate school of civil engineering such as that described!"

*Higher Education for Civil Engineers. An Address to the Engineering Society of the University of Nebraska, April 8, 1904, by J. A. L. Waddell, D. Sc., LL. D.

Another extremely practical and effective means for affiliating civil engineering and the other sciences is for engineers and professors of both pure science and technics to establish the custom of associating themselves for the purpose of solving problems that occur in the engineers' practice. Funds should be made available by millionaires and the richer institutions of learning for the prosecution of such investigations.

Another possible (but in the past not always a successful) method, is the appointment by technical societies of special committees to investigate important questions. The main trouble experienced by such committees has been the lack of funds for carrying out the necessary investigations, and the fact that in nearly every case the members of the committees were unpaid except by the possible honor and glory resulting from a satisfactory conclusion of their work.

Finally, an ideal but still practicable means is the evolution of a high standard of professional ethics, applicable to all branches of engineering, and governing the relations of engineers to each other, to their fellow workers in the allied sciences, and to mankind in general.

As an example of what may be accomplished by an alliance of engineering and the pure sciences, the construction of the proposed Panama Canal might be mentioned. Some years ago the French attempted to build this waterway and failed, largely on account of the deadly fevers which attacked the workmen. It is said that at times the annual death rate on the work ran as high as six hundred per thousand. Since the efforts of the French on the project practically ceased, the sciences of medicine and biology have discovered how to combat with good chances for success the fatal malarial and yellow fevers, as was instanced by the success of the Americans in dealing with these scourges in the City of Havana after the conclusion of the Spanish-American war.

The success of the American engineers in consummating the great enterprise of excavating a navigable channel between the Atlantic and Pacific Oceans (and concerning their ultimate success there is almost no reasonable doubt) will depend largely upon the assistance they receive from medical science and its allied sciences, such as hygiene, bacteriology, and chemistry.

Geological science will also play an important part in the design and building of many portions of this great work, for a comprehensive and correct knowledge of the geology of the Isthmus will prevent the making of many costly mistakes, similar to those that resulted from the last attempt to connect the two oceans.

Again, the handling of this vast enterprise will involve from start to finish and to an eminent degree the science of economics. That this science will be utilized to the utmost throughout the entire work is assured by the character and professional reputation of both the Chief Engineer and the members of the Commission.

Notwithstanding, though, the great precautions and high hopes for a speedy and fortunate conclusion of the enterprise with which all concerned are starting out, many unanticipated difficulties are very certain to be encountered, and many valuable lives are likely to be expended on the Isthmus before the first steamer passes through the completed canal. Engineering work in tropical countries always costs much more and takes much longer to accomplish than is at first anticipated; and disease, in spite of all precautions, is very certain to demand and receive its toll from those who rashly and fearlessly face it on construction works in the *tierra caliente.* But with American engineers in charge, and with the finances of the American Government behind the project, success is practically assured in advance.

What the future of civil engineering is to be, who can say? If it continues to advance as of late by almost geometrical progression, the mind of man can hardly conceive what it will become in fifty years more! Every valuable scientific discovery is certainly going to be grasped quickly by the engineers and put to practical use by them for the benefit of mankind, and it is only by their close association with the pure scientists that the greatest possible development of the world can be attained.